Dam Safety Reviews

Best Management Practices

Ontario Ministry of Natural Resources

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The Lakes and Rivers Improvement Act (LRIA) provides the Minister of Natural Resources with the legislative authority to govern the design, construction, operation, maintenance and safety of dams in Ontario. These best management practices have been prepared to provide Ontario dam owners with guidance on the safe management of dams. These best management practices are recommendations only and are not to be considered when seeking approval under Section 14, 16 and 17.2 of the LRIA.

Dam Safety Reviews

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1.0 General

The Dam Safety Review (DSR) is a systematic review and evaluation of all aspects of design, construction, maintenance, operation, and surveillance, and other factors, processes and systems affecting a dam's safety. The Review defines and encompasses all components of the "dam system" under evaluation (including dam, spillway, foundation, abutments, reservoir, tailraces, etc.). The evaluation should be based on current knowledge and standards, which may be different from the acceptable standards at the time of original construction or a prior DSR. These inspections should be documented in a report and appended to or form part of the DSR and assessment. This report should also outline the frequency, scope and content for a DSR, and addresses the need for independence in the Reviewer, and follow-up on the findings.

These best management practices have been prepared to provide dam owners with guidance on conducting DSRs. DSRs are recommended for High or Very High Hazard Potential Classification (HPC) dams. While a DSR may not be required for Low and Moderate hazard potential dams, a periodic review of the hazard potential classification should be completed every ten years to determine whether a change in the classification of the dam is warranted due to upstream or downstream changes in the watershed.

These best management practices should be read in conjunction with the Ministry of Natural Resource's Classification and Inflow Design Flood Criteria Technical Bulletin.

1.1 Review Team

The review is to be carried out by a registered Professional Engineer (Review Engineer) or multidisciplinary team reporting to the Review Engineer, who are qualified by their background in design, construction, performance analysis and operation of dams. The Terms of Reference of the DSR should clearly identify the accountability for the final review report.

The term "Reviewer" is used in this document to mean Review Engineer or members of the review team reporting to the Review Engineer.

1.2 Independent Review

The dam owner is responsible to ensure that the Review Engineer is able to complete the DSR in an impartial and objective manner.

In general the review findings should be free of any conflict of interest that could be caused by prior participation of the Reviewer in the design, construction, operation, maintenance or inspection of the dam under review. It is also advisable that the same Review Engineer not carry out two consecutive DSR of the same dam. The intent is to encourage dam owners to benefit from a range of perspectives which can lead to previously undetected performance issues being identified; as well as to be consistent with the notion of having the review findings independent of any conflict of interest.

1.3 Frequency of Review

The recommended frequency for conducting a DSR depends on the hazard that the dam presents, the presence of or changes to external hazards, the results of surveillance and the demonstrated performance. For new dams, it is important that all design and construction records be preserved and catalogued for easy retrieval when a DSR is to be undertaken. It is suggested that documentation be compiled as the design proceeds, to ensure that all dam safety aspects have been addressed and to reference all relevant design documents. This process could be considered a "Design Phase Dam Safety Review", and the documentation would also serve as a starting point for the first post-commissioning DSR. It is important that as-built drawings be produced to show any changes made from the original design drawings, the reasons for the change and any unusual site conditions observed during constructions. It is recommended that the first post commissioning DSR of a new dam be completed within three years of initial filling of the reservoir.

During its operational life, any significant change affecting a dam should trigger a DSR or appropriate investigations. Significant changes include, but are not limited to, changes in stage of construction of tailings dams, construction modifications to the original dam design, discovery of unusual conditions, new dams on the river system, new developments downstream of the dam, new knowledge of safety analysis, new standards of safety and extreme hydrologic or seismic events. Should these significant changes result in a recommendation for dam decommissioning, a study and assessment of all hydrologic, environmental and physical impacts should be undertaken.

Tailings dams and their facilities can be evolving structures, the construction of which may continue over the entire active life of the facility. During the life of the structure(s), the requirements for safety, maintenance, operation and surveillance may change, as may the appropriate frequency of DSRs, if the incremental losses associated with a potential dam failure change. The DSR of a tailings dam should take into account the dam safety requirements applicable to all future operating phases.

For tailing dams, often an inspection and monitoring program is undertaken for many years after closure, with periodic reviews and assessment of the post closure performance. For all dams, at the completion of one review, the date for the next review should be set. The maximum recommended period between DSRs based on the dam's hazard potential consequence classification is shown in Table 1. If surveillance or other observations indicate abnormal performance, a review should be initiated sooner than indicated in Table 1. Closure of a mine tailings dam does not imply that a dam has been decommissioned.

For owners with a portfolio of many dams, if it is necessary to prioritize DSRs among dams with similar classifications, consideration should be given to the performance of the dams and to any known problems or issues that have emerged since the prior DSR.

Table 1 - Maximum Recommended Period Between Dam Safety Reviews

Hazard Potential Classification Category	Period Between Review
Very High and High[1]	10 years

Low and Moderate[2]	10 year review of HPC

i. The maximum recommended period between DSRs for High and Very High hazard classification dams should be ten years however dam owners may wish to consider a greater frequency of reviews depending on the potential risks to public safety
ii. Low and Moderate hazard potential dams are recommended to complete a periodic review of the hazard potential classification every ten years to determine whether a change in the HPC is warranted
iii. DSR includes the following: collection of all available dam records, field inspection, detailed investigations and possibly laboratory testing. It then proceeds with a check of structural stability and operational safety of the dam, beginning with a reappraisal of basic features and assumptions. The level of detail required in a DSR must commensurate with the importance and complexity of the dam, as well as the consequence of failure.
iv. DSR should be conducted within 3 years after initial filling. This Review will also establish the frequency of subsequent DSRs.

1.4 Level of Detail

The level of detail in the DSR should be sufficient to demonstrate that the dam structure and its operation, maintenance and surveillance meet the principles of safe dam management. The level of detail may be modified on the basis of previous assessments, complexity of the dam, continuity of surveillance and records, external and internal hazards, operating history, dam performance and age, and the need for public protection during operation. If the information since the last review is complete and continuous, the current review may be simplified.

2.0 Scope of a Dam Safety Review

The scope of a DSR may vary from dam to dam according to the HPC and other circumstances.

A DSR is required to demonstrate that the dam is safe, operated safely and maintained in a safe condition, and that surveillance is adequate to detect any developing safety problem. The review generally includes site inspection, review of all relevant documentation, and interviews with operating and maintenance staff. If safety cannot be demonstrated, the deficiency should be identified.

Records of any dam safety incidents since the previous review and follow-up actions should be reviewed. Testing of flow discharge equipment should be carried out. If the equipment has been operated within a reasonable time frame, it need not be tested, but records of the last operation and the performance records of the equipment should be reviewed.

3.0 Dam Safety Analysis

Safety analysis of the dam system should include the internal and external hazards, failure modes and effects, operating reliability, dam response, and emergency scenarios. The interaction of human factors, organization and equipment and the potential for errors, misunderstandings or mis-interpretations should be examined. The design of the dam should be reviewed to determine whether the dam, discharge facilities and reservoir slopes meet applicable safety requirements. Although various features are reviewed individually, the way they interact and function as a system should also be considered. The construction and operation should be reviewed to ensure that the design intent has been achieved. The review of the design as it relates to the present condition of the "as constructed", "as operated" dam should include but not be limited to the consideration of the following, as applicable:

1. Construction records to determine how closely the as-constructed dam conforms to design assumptions and to establish the adequacy of dam and foundation materials;
2. Adequacy of the derivation of extreme events, floods and earthquakes for which the dam is designed, taking into account any extreme events that may have occurred since the commissioning of the dam;
3. Structural stability, seepage and erosion resistance of all portions of the constructed water barriers including their foundation, as well as any natural water barriers under normal and extreme loading conditions, including the effects of permafrost;
4. Spillways must be capable of discharging the design flows safely, be able to adequately pass the inflow design flood and to draw down the reservoir if required in an emergency;
5. Design of all gates, valves, intake flow control equipment and hoists, including controls, power supply and winter heating criteria, to ensure timely, safe and reliable operation. The level of reliability needed for the flood discharge facilities depends on the repair time available between the start of an extreme flood and overtopping of the dam should the gates not be opened. These discharge facilities must function after an earthquake to the extent necessary to maintain safe reservoir levels;
6. Operating rules under various conditions, and their conformance with the design intent and criteria;
7. Adequacy of the as-constructed facilities to deal with special phenomena affecting safety (for example, debris, ice conditions and erosion) that may have been insufficiently considered at the time of design and construction as well as verification that they will function as and when required;
8. Potential failure modes and criticality, and adequacy of design, construction and operation features addressing these failure modes; and
9. For tailings dams, design parameters such as tailings and water chemistry, tailings characteristics, tailings beach development, discharge points, pond level and location, and water balance.

Co-operative agreements and agreed operational restrictions in place should be reviewed and assessed. Owners of dams in cascade or on parallel systems with common areas of impact should coordinate with respect to operations, spill capacities, emergency response and any other issue of mutual concern.

4.0 Site Inspection

All DSRs should include a site visit so that the Review Engineer or review team observes actual conditions of the entire dam system. The dam, dam instrumentation, discharge facilities, outlet works, downstream areas that could be inundated by a hypothetical dam breach, reservoir, reservoir slopes, and water instrumentation (i.e. water level gauges upstream and downstream) should be included in the site inspection. The inspection should note any debris accumulation upstream of the dam and potential for debris accumulation under high inflow conditions. The general stability of the reservoir slopes and evidence of slides or instabilities should be assessed and noted. Depending on the area's geology and topography, study of recent air photos and comparison with historic photography, as well as a fly-over inspection, may be necessary.

If the dam is exposed to conditions other than those occurring during the site inspection, efforts should be made to investigate the effects of these conditions by other means. For example, in regions of extreme winters, the Review Engineer should examine records and/or photographs of the dam's winterized conditions and assess the winter ice formation and loading and any associated problems. Similarly the effects of other extreme climatic conditions should be assessed as appropriate. Reservoirs subject to significant operational draw-downs should be inspected with the reservoir full as well as under drawdown conditions.

The extent of the area that should be inspected downstream of a tailings dam will depend upon the nature of the tailings, basin characteristics and foundation conditions. The inspection should include sampling of water quality, environmental conditions, noting any stressed vegetation, discoloration of the ground and unnatural deposits at regular or intermittent watercourses.

Where the dam has deteriorated with age, field investigations should be carried out to determine critical characteristics existing at the time of the review.

5.0 Staff Responsibilities

A meeting or interview with staff responsible for the operation, maintenance and surveillance of the dam can be beneficial in providing the Review Engineer with further information and insight into operating and maintenance issues or incidents, the equipment or system issues, the dam performance, and generally on the level of training and knowledge of the staff. The Review Engineer should also assess the staff familiarity with the river system, the presence of other dams on the system, their operations and any coordination or integration issues, any public safety issues and other stakeholder's interests.

These interviews are best done informally during the course of the site visits and inspections. The review should address the capability and availability of the operators assigned to the dam, to ensure that discharge facilities can be operated in a timely manner. This review should also consider their normal hours of operation, reaction time to the site relative to potential rate of reservoir rise under large floods, availability of emergency power supplies, and access under all weather conditions. Any deficiencies in training should be noted and recommendations made.

If deficiencies in operator availability are noted, consideration should be given to recommending additional staff or to remote operation of the facilities. The Reviewer should also ensure that there is proper delegation of authority to operate the discharge facilities. The operating authority should be reviewed, including the communication to higher authorities. Regardless of the local lines of authority and communication facilities, the local operators should be empowered with the authority to operate the discharge facilities if water levels endanger the dam.

6.0 Documentation and Items to be Reviewed

6.1 Hazard Potential Classification

During the DSR, the HPC of the dam failure should be reviewed. The primary reason that the classification could change is new development in the flood plain downstream of the dam which would increase the damages from dam failure or the identification of environmental or socio-economic losses that were previously unaccounted for. If the classification has not previously been determined, it should be established during the DSR.

6.2 Records and Data Collection and Effectiveness Monitoring

A DSR requires an understanding of the construction methodology, conditions and practices used for the construction of that dam. Ideally, a complete set of records should be available for every existing dam. Record keeping should start at the early planning stage and continue throughout all phases of the dam's service life, recording any relevant information on planning, field investigations, laboratory testing, design decisions, construction and quality control, first reservoir filling, operation, maintenance, repair, and any modernization or enlargement. The records should include: design calculations; equipment specifications; as-built documents; registered data from hydrological, structural (including seismic) and operational monitoring; and all safety inspection reports. If such records are generally available, the periodic DSR is facilitated.

In the case of unacceptable performance, recommendations can be based on updated knowledge of the dam's actual state of structural integrity, compared to its past operational behaviour. A continuous set of design and service records provides a reliable basis to support decisions on dam safety improvements. Generally, the older the dam, the lower the likelihood is of finding usable documentation on its design, construction and operation. Interviews with staff, usually retired, who have contributed to

the design and construction of the dam can be a very important source of information. Often photos and videos either in archives, or personal files kept by retired or current staff, can shed light and provide missing information and details on the site construction and repairs or upgrades during its life stages.

Since the acquisition of the missing data can be expensive and time-consuming, it should be preceded by a careful determination of the type, amount and detail of data actually needed to assess the structure's safety and reach sufficiently reliable conclusions. The first step will be a critical evaluation of the records of peak floods available from third parties, repair accounts, old reports of dam tenders and maintenance personnel, and other indirect information which may be obtained. A field visit will reveal areas and items of major concern such as material deterioration, excessive deformation, high seepage, equipment deficiencies, and others. The field visit will also help to determine the scope and extent of specific investigation programs.

Following the site visit and review of records, a list of information gaps should be prepared and the dam owner advised of the assumptions that must be made to fill the gaps or the additional data that is required in order to proceed. A topographic survey can be used as the basis for new drawings of the existing structures or to complement available drawings. If the original design computations and material specifications are unavailable, contemporary standards and text books may furnish some information on design criteria and methods which most probably were used, safety factors and the properties of then-available materials.

Hydrological records are generally available for some periods of the dam's operation. If the available data are insufficient for hydrologic reassessment, correlation with records from neighbouring drainage areas may be acceptable. Another source of information could be precipitation records which can be used to determine runoff and flow data. This data may serve as direct input to flow computations, or as a means to check and calibrate correlations. Above all, careful judgment based on sound theoretical knowledge and broad experience must be used for the analysis and correct interpretation of both primary and secondary (indirectly obtained) data. In all cases the report must clearly state the origin of data used in the analysis and the assumptions that have been made.

6.3 Previous Dam Safety Reviews

During the first DSR all existing data should have been assembled and supplemented with field investigation and data gathering. Design analysis should have been carried out, deficiencies identified and recommendations made for improvements. For this reason, subsequent periodic DSRs can be structured more as an audit of the previous information, ensuring that it is complete, up to-date with current standards, that the conclusions reached and recommendations made were appropriate and remain valid.

Therefore, if one or more DSRs have been carried out in the past, the Review Engineer should start with a review of the previous dam safety reports. Changes in status or condition between those described in previous reports and those found by the current review should be noted, and trends should be determined. The extent of implementation of recommendations from previous reports should also be determined.

The DSR should utilize information developed in any previous review, to the extent that its reliability and validity can be verified.

7.0 Operation, Maintenance and Surveillance

Any existing Operation, Maintenance and Surveillance plan(s) (OMS) should be reviewed to confirm effectiveness to meet its objectives, and to confirm the owner's compliance with that plan.

The DSR should determine:

1. If safe operating procedures have been developed, documented and followed, and if contingency plans are in place which contain sections on describing operations for low flow conditions, normal flow conditions, emergency conditions, and unusual conditions. The adequacy of the documentation is to be reviewed;
2. If all facilities required for the safety of the dam, including precipitation and water level gauges, snow survey stations and dam monitoring instrumentation, are maintained in satisfactory condition in accordance with the OMS Plan and any detailed instrument manuals;
3. If the surveillance and monitoring methods and frequency are adequate to detect any unsafe condition in a timely manner and if monitoring data has been regularly analyzed and used to ensure prompt detection of any potentially unsafe conditions in the dam, associated water containment and reservoir slopes;
4. If there are adequate debris management procedures to ensure that spillways are not blocked or their discharge capacity reduced by debris;
5. Similarly, for dams in cold regions, if there are adequate ice management procedures to ensure the spillways are not blocked by ice when they are needed to operate (for example in early spring);
6. If the maintenance procedures and frequency of maintenance are adequate for the dam and its components, including gates and other discharge facilities, power supply, cranes, motors and hoists and foundation drains;
7. If there are adequate vegetation control procedures for the dams. Compliance with the documented procedures can be assessed by audit of operation, maintenance and surveillance records, discussions with site personnel, and by judging the state of maintenance and site conditions during the site visit; and
8. Any instances of non-compliance with conditions of approval or plans.

8.0 Flow Control Equipment Testing

The DSR should address the testing of equipment required to operate discharge facilities (including backup equipment and emergency power supply) that are required for the safe passage of the inflow design flood, and any other flood that could endanger the dam. If the discharge gates and equipment have been tested or operated within the year, and adequate documentation is available, a review of such testing or operation

records may be adequate for the DSR. Otherwise the testing can be carried out during the DSR. The DSR should also determine:

1. If the flow control equipment is maintained in good working order and tested regularly to ensure it would function reliably when called upon to operate;
2. If incidences of malfunction are promptly reported, investigated and addressed to prevent recurrence; and
3. If back up equipment required in the contingency plans (such as alternate power supplies) are available and accessible within an adequate time frame.

9.0 Emergency Preparedness

Any existing Emergency Preparedness Plans (EPP) and response procedures should be reviewed. The DSR should determine if the appropriate level of emergency preparedness exists and is adequately documented. The adequacy of warning systems, training and emergency response plans should be reviewed, as well as the frequency of testing and the processes in place for document control. The DSR should ensure that the notification lists are maintained and that a sufficient process is in place to keep it updated and communicated to external contacts. The DSR should also determine if findings and lessons learned from incidents or from emergency drills are properly documented and followed up within a reasonable time.

10.0 Security Requirements

Some dams, in view of their size, location, purpose and potential losses associated with a dam failure, can be considered critical infrastructure that merit special security measures. In carrying out the DSR, the Review Engineer should verify that such measures are in place and are in conformance with the requirement of the appropriate Provincial or Federal Department or Agency responsible for infrastructure security. The Reviewer should verify that operating equipment is secured against vandalism or inadvertent operation by unauthorized individuals, and that the dam management process ensures that any incident of security breach or vandalism is reported and addressed in a timely manner.

11.0 Public Safety Around Dams

Any physical public safety measures installed or implemented at the site should be reviewed to ensure that they continue to remain operational and represent current practice.

12.0 Dam Safety Review Report

The DSR should be documented by the Review Engineer in a formal report with conclusions and recommendations to permit the dam owner to fulfill the responsibility for dam safety. This report should cover all aspects of the dam's safety and to document the

DSR. The report should clearly detail and quantify deficiencies in the structure, non-compliance with policies, guidelines or standards, and any other issues requiring follow-up, such as priorities for safety improvement, remedial measures or additional investigations. It should also identify any additional steps required for operation, maintenance and surveillance according to regulatory requirements or industry recognized best management practices. Where past documentation was inadequate or absent, the Reviewer should report this information gap and identify where potential deficiencies may exist and what further actions may be needed.

The initial methods of analysis used in the Review, or the data available, may be insufficient to clearly demonstrate an acceptable level of safety for the dam, discharge facilities or reservoir slopes. If additional work is needed to evaluate and document dam safety, the DSR report should include recommendations for more extensive analysis or investigations to provide adequate data for analysis.

Upon completion, the Review Engineer should date, sign and certify the DSR Report. It is the responsibility of the dam owner to retain a copy of the DSR report.

Glossary of Terms

Dam Safety Review: a systematic review and evaluation of all aspects of design, construction, maintenance, operation, and surveillance, and other factors, processes and systems affecting a dam's safety.

List of Acronyms

DSR	Dam Safety Review
EPP	Emergency Preparedness Plans
HPC	Hazard Potential Classification
LRIA	Lakes and Rivers Improvement Act
MNR	Ministry of Natural Resources
OMS	Operations, Maintenance and Surveillance Plans